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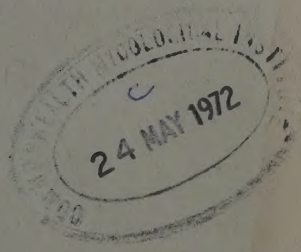
THE CONTROL OF CACAO SWOLLEN SHOOT DISEASE IN WEST AFRICA

A Review of the Present Situation

J. M. THRESH



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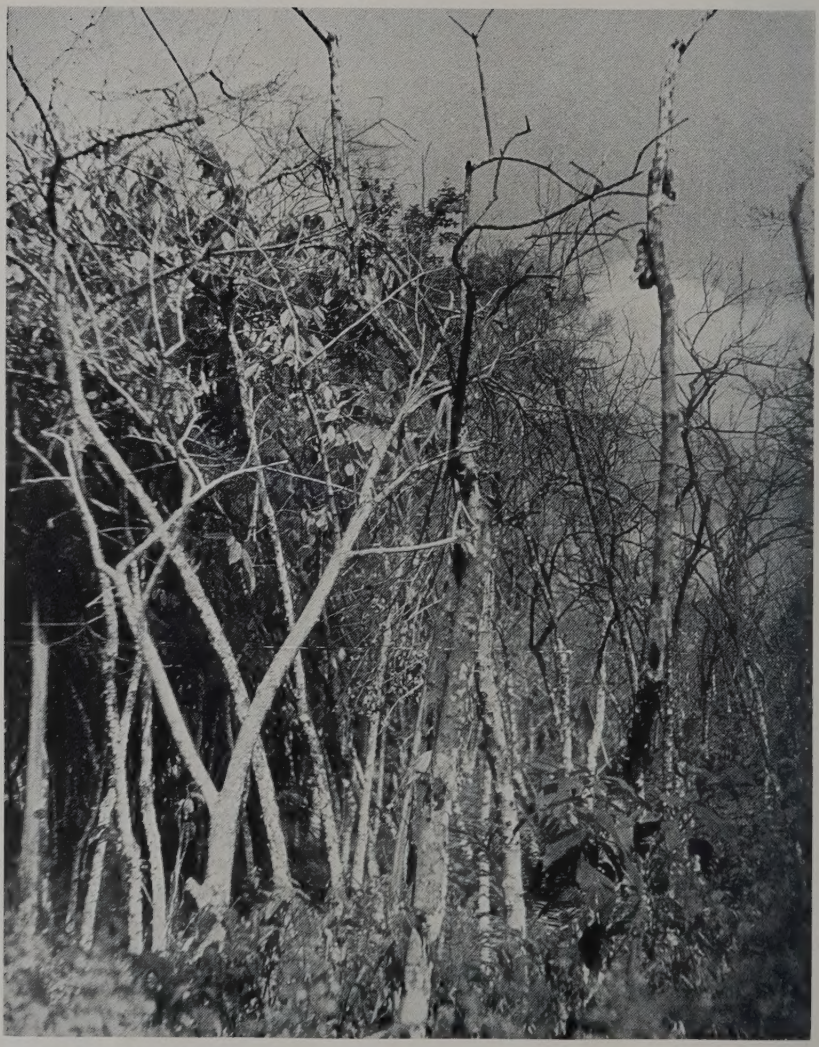

A general view of a cacao farm which has been devastated by Swollen Shoot Disease.
Photograph taken in the Eastern Province of Ghana.

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METHODS OF CONTROLLING CACAO SWOLLEN SHOOT DISEASE IN WEST AFRICA— A REVIEW OF THE PRESENT SITUATION*

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*This review is based on publications which appeared before November, 1957, but also refers to additional papers which have been seen in manuscript.

INTRODUCTION

In 1938, Posnette (1940) showed that the swollen shoot condition of cacao in Ghana was caused by a virus. Since that date, virus infection in cacao has been demonstrated in Nigeria, Ivory Coast and in various other parts of the world. In West Africa, the viruses attacking cacao are usually referred to as causing cacao swollen shoot disease. This disease is one of the most important factors limiting the production of cocoa and is one of the most economically important plant diseases in the world. In Ghana and in Nigeria, sixty-five million infected trees have been destroyed in unsuccessful efforts to eradicate the disease from these countries (see Appendix I). In addition, many more trees were killed by the unrestricted spread of swollen shoot disease before control measures were started, while losses continue in heavily infected areas where these measures have been temporarily abandoned.

The magnitude of the swollen shoot disease problem has justified extensive investigations into the disease and the viruses which are its cause and a sequence of workers has been engaged on the problem during the last nineteen years in Ghana and during the last four years in Nigeria. Much of the work has involved an investigation of the possible methods of curing infected plants and of checking the spread of infection in the field. These investigations have revealed a most complex association in which not only cacao host, virus and vector are involved, but also many species of ants and several indigenous forest trees, which are relatives of cacao. Work on the cure and control of cacao swollen shoot disease in West Africa is summarised and discussed in the present bulletin, which is based on published papers and numerous references in the Annual Reports of the West African Cocoa Research Institute.

THE CURE OF INFECTED PLANTS

Plants infected with a virus disease do not usually recover, but remain infected until they die. However, some viruses may be eliminated from certain hosts by heat treatment (Kassanis, 1957) or chemotherapy (Matthews & Smith, 1955) and these two methods have been tried with swollen shoot virus in cacao.

A. Heat Therapy

In some of the earliest work on cacao swollen shoot virus, Posnette (1943a, 1947a) established that viruses from the New Juaben and Bisa areas of Ghana were not inactivated when infected budwood was immersed in water at 45°C. for thirty minutes, at 50°C. for twelve minutes, or at 52°C. for ten minutes. More drastic treatments killed the budwood and it was concluded that heat treatments which were not fatal to the host tissue had no noticeable effect on the viruses.

Todd (1951a) also investigated the effect of different heat treatments on the virus from New Juaben, but used a different technique. Insects carrying the virus were fed on the embryos of dissected beans (Posnette, 1947b) which were then kept in a dark incubator maintained at 37.5°C. for various periods. Under these conditions germination was checked or entirely prevented, but the cotyledons survived and could be tested for the presence of virus at various intervals after planting in the heated chamber. Using mealybugs it was usually possible to detect virus in the cotyledons which had been kept in the chamber for periods of four or five weeks. In similar tests virus was not transmitted from some of the cotyledons which had been treated for five, six or eight weeks. This may have been an effect of the heat treatment but the interpretation of the results is equivocal. The inability of mealybugs to transmit virus from some of the cotyledons may have been due to a deterioration in the condition of the beans during incubation, or to failure of the original infestation to infect them. That heat treatment was having little effect on the virus in these experiments was indicated by the observation that the few treated beans which germinated, grew into infected plants. These showed symptoms typical of infection with the virus from the New Juaben area and there was no indication that it had been attenuated.

In more recent work Lister & Thresh (1957a) used a heated chamber of the type used by Kassanis (1954) and investigated the effect of heat treatment applied to cacao seedlings infected with isolates of virus collected in Nigeria. Infected seedlings were grown at 38°C. for periods up to four weeks. Leaves with symptoms were

produced while the plants were in the heated chamber and later when moved to unheated glasshouses. The treatment did not eliminate the viruses and had no obvious effect on the type of symptoms produced.

B. Chemotherapy

Many experiments have been carried out to investigate the effect of a range of chemicals on the multiplication of cacao swollen shoot virus in cacao tissues. In the first trials, Todd (1951a) placed mealybugs carrying the virus on to dissected beans which were subsequently immersed in solutions of quinhydrone or other organic materials which had been shown to have a therapeutic effect on peach tissues infected with X disease (Stoddard, 1947). Most of the inoculated beans which survived the chemical treatment grew into infected plants in the usual way.

In more extensive trials, Hunter (1953) used a large number of inorganic and organic compounds, at a range of concentrations, to determine whether any of these materials would eliminate virus from infected cacao tissues, or make healthy tissues immune or resistant to infection. In some experiments branches or dissected beans were immersed in the chemicals to be tested, while in other trials injection methods were employed or the materials were watered on to the roots of seedlings. Full details of the techniques and results are not presented, but none of the chemicals had any therapeutic effect, nor did they affect symptom expression or the susceptibility of plants to infection.

The most recent investigations have been carried out by Holden (1957) who applied thiouracil and 8-azaguanine to germinating beans inoculated with virus from New Juaben or from Kpeve. Both compounds increased the severity of the virus symptoms, although they had no visible effect on healthy plants. In additional tests beans were treated with thiouracil or 8-azaguanine before infesting them with mealybugs from a virus source. This chemical treatment did not prevent normal feeding and had no effect on the subsequent development of virus symptoms.

THE CONTROL OF CACAO SWOLLEN SHOOT DISEASE

Although it may eventually be possible to cure infected cacao plants, there is no immediate prospect of a method being evolved which could be used on a field scale. Control measures against cacao swollen shoot disease are thus restricted to methods of reducing the spread which normally occurs by the movement of mealybugs from infected

to healthy plants. Possible methods of reducing spread include the use of immune or resistant varieties of cacao, protective immunisation, eradication measures, insecticides or biological control. All these and other measures have been investigated and are discussed in the following sections.

A. Use of Immune or Resistant Varieties

The existing cacao in West Africa is predominantly of the Amelonado type and one method of dealing with swollen shoot disease would be to replace this highly susceptible material by varieties which are immune to the disease. Unfortunately immune varieties are not yet available and Posnette & Todd (1951) who tested samples of all the available cacao breeding material in Ghana, including local and introduced selections, obtained results suggesting that all the material could be infected with a virus collected from the New Juaben area. They did find, however, that some seedlings of Upper Amazon parentage were more difficult to infect with this virus than Amelonado cacao and also that some of the tested seedlings showed inconspicuous symptoms and appeared to be tolerating infection. These observations are of great importance, because in the absence of immune cacao a satisfactory alternative might be to use resistant varieties. Resistant varieties which show only mild symptoms when they become infected may be of particular value, but only if their ability to tolerate infection is associated with low virus availability. Otherwise infected plants would not only be difficult to detect, but would at the same time act as dangerous foci of infection to surrounding areas of healthy cacao, which may well be of a more susceptible variety.

Posnette & Todd (1951) concluded that the level of resistance found in their experiments was not sufficiently high to be of immediate practical value. Nevertheless, their work was continued by Dale (1957) who investigated the effect of virus isolates from New Juaben and other areas on seedlings and also on rooted cuttings taken from some of the original Tafo plantings of Amazon cacao. It was established that some selections show resistance and tolerance to infection with the New Juaben virus and also to the dissimilar virus from Kpeve. This is a significant observation and may indicate that plants which are resistant to the New Juaben virus may also be resistant to the mealybug-transmitted cacao viruses present in other areas. Further information is required on this point and also on the yield performance of resistant and tolerant varieties when they become infected. Additional work is also required to elucidate the inheritance of the factors for resistance and tolerance and also to indicate whether

it will be necessary to use rooted cuttings of the resistant material, or whether the desired characters may be obtained by the more convenient method of using seed of known parentage.

The time now seems appropriate to test some of the most promising material under field conditions in localities where it will be subject to natural infection by different viruses. If commercially acceptable varieties can be found which show field resistance and also tolerance, so that they continue to yield satisfactorily even though they are infected, they might be particularly valuable in heavily infected areas, where there is a high risk of infection and where extensive replanting is following widespread cutting out operations. It should be pointed out, however, that even if satisfactory varieties can be introduced to replace the existing cacao, the changeover could only be a gradual one and the problem of dealing with virus in the present Amelonado population will remain for many years.

B. Mild Strain Protection

The use of mild or attenuated virus strains to confer protection against virulent forms of the same virus is well established in medical and veterinary practice, but has not been used on a widespread scale as a method of protecting plants from harmful virus effects. This is largely because plant tissues, unlike those of animals, must be actually infected with mild virus if they are to resist subsequent infection with a related virulent one. Consequently, before the dissemination of a mild strain of a plant virus can be considered, it is essential to obtain stable and sufficiently mild forms which consistently protect against severe prevalent forms of the same virus and yet have no harmful effects, either alone or in combination with unrelated viruses. These difficulties are formidable ones which must be overcome before the method can be recommended for the general control of a plant virus disease. Nevertheless, there are possibilities of controlling cacao swollen shoot disease in this way and these were appreciated at an early stage of the investigations at Tafo (Posnette, 1943a).

In preliminary tests, the apparently mild virus from Bisa had given some protection against the virus from New Juaben and a large scale field trial was set up to investigate the relationship between the two viruses in greater detail (Crowdy & Posnette, 1947). This experiment showed that trees inoculated with the Bisa virus became infected with New Juaben virus less rapidly than controls which were not inoculated. However, protection was not complete or permanent and most of the trees in the experiment were eventually killed by the spread of the more virulent virus (Dale, unpublished information). The Bisa virus alone had no detectable effect on yield, but it was clearly of

little practical value as a means of protecting plants from the effects of the common New Juaben virus and work on these lines was discontinued.

In later investigations, Posnette & Todd (1951) isolated viruses having very mild effects on cacao, from surviving trees present in farms in the Eastern Province of Ghana which had been devastated by virulent strains of virus. The mild isolates protected plants from subsequent graft infection with severe strains and some of them had no appreciable effects on the growth of seedlings. Further studies on the complex of viruses occurring in the New Juaben area were described by Posnette & Todd (1955). It was established that one of the mildest isolates had little effect on the yield of inoculated trees and usually protected them from the effects of virulent virus. However, protection was not always complete and plants inoculated with a mild virus sometimes became infected with virulent strains; an observation which was subsequently confirmed by Attafuah & Dale (1957).

Despite the occasional breakdown of protection, further field experiments are justified to investigate the practical application of mild strains on a large scale. Mature trees or new planting material might be infected with mild strains to protect them from the effects of virulent strains in areas where these are widely distributed in the mature cacao. Furthermore, the mild strains could be used to infect the apparently healthy trees around virus outbreaks as a possible method of checking spread in areas where it is not practicable to apply eradication measures.

Of these various possibilities it seems doubtful if mild strains of virus could be introduced into mature trees of farmers' cacao on any extensive scale. However, mild strains might be of considerable value in heavily infected areas, if introduced into seedlings or rooted cuttings before planting them out. Cuttings could be taken from parent trees which had previously been infected with a mild virus, while seedlings could readily be infected by means of simple patch grafts. Thus planting material could be infected with only slight modifications of current nursery practice. A more important limitation of the use of mild viruses is that the ones which have been investigated in detail at Tafo will only protect plants from the effects of what appear to be a closely related group of viruses. These include an isolate from Kongodia in French Ivory Coast, and viruses occurring over an extensive area around New Juaben in the Eastern Province of Ghana (Tinsley, 1955). Consequently, experiments on the use of the mild strains which are available at the present time will have to be restricted to these areas, where they may have application on an extensive scale. Mild strains may be particularly valuable in

the Eastern Province of Ghana, where considerable difficulty is being experienced in preventing the spread of virus into young cacao. This is illustrated by the fact that almost half the sixteen million trees which had been cut out in the so called 'resumed' area by 1957 had been recently planted and had not come into bearing at the time they were cut out. (Hammond, 1957).

There is no reason to think that the mild viruses collected in the New Juaben area are at all unique and recent investigations carried out in Nigeria (Thresh, unpublished information) suggest that mild viruses can be isolated from trees occurring in most large outbreaks. It was found that viruses which are virtually latent in cacao could be isolated without difficulty from the three outbreaks which were investigated in detail. The method usually used to obtain these viruses was to carry out transmissions from trees which showed only very inconspicuous symptoms and these only at infrequent intervals. Alternatively, it was sometimes possible to obtain mild viruses from the vigorous, symptomless shoots occasionally produced after coppicing infected trees, or by a process of selection in a series of laboratory transmissions using mealybugs.

The relationships of the mild viruses recently collected in Nigeria to the commoner viruses are at present under investigation. It is at least possible that these mild viruses alone, or in combination as a 'bulk inoculum', might protect plants from the effects of some or all the viruses now widespread in the two abandoned areas of mass infection, where millions of infected trees are known to occur (Lister & Thresh, 1957b). If this is established, there are obvious possibilities in replanting at least parts of the areas with material infected with mild virus. Similarly, it may be worth searching for mild viruses in heavily infected parts of Ghana, other than the New Juaben area.

Assuming that sufficiently mild strains of virus can be found and that they confer an adequate degree of protection against local and more virulent viruses, there seems to be no great danger in their use in particular areas. Mild viruses are already present in many outbreaks and there is some evidence that they are tending to build up at the expense of the more virulent viruses, which either kill their host or are relatively easily detected and eradicated by the survey parties. It follows that a system of controlled replanting making use of mild viruses, may be a desirable alternative to the present uncontrolled planting by peasant farmers, which enables the cycle of virulent strain infection to continue.

The risk of a mutation to a particularly virulent form of virus has to be considered, but there is no reason for thinking that this possibility is likely to be any greater in trees infected with mild virus than it is in the many trees already infected with virulent ones in the areas

where eradication measures are not practised in Ghana and in Nigeria. A more cogent argument against the use of mild strains is that they may spread into the less heavily infected areas and be difficult to eradicate, as the symptoms they produce are not easily recognised. However, the indications are that virus is not readily available to mealybugs feeding on trees infected with mild strains (Posnette & Todd, 1955; Thresh, 1957) and these are unlikely to spread rapidly. Moreover an increase in the number of trees infected with mild viruses is probably a satisfactory alternative to the continued, uninterrupted spread of both mild and severe viruses from the present abandoned areas.

C. The Insect Vectors of Swollen Shoot Disease and Their Biological Control

Several species of mealybugs (Homoptera: Pseudococcidae) were found by Posnette (1950) to be capable of transmitting cacao swollen shoot virus. Following this discovery detailed investigations into the size and composition of the mealybug populations on the cacao in Ghana were carried out by Strickland (1947, 1951a, 1951b). It was found that 98.9 per cent. of the specimens collected at Tafo were of the species *Pseudococcus njalensis* Laing and a mean population of 65.7 bugs per tree was recorded on the 2,880 mature trees which were felled and examined in detail. *P. njalensis* was found to be frequently attended by ants and this association was subsequently investigated by Cornwell (1953, 1956, 1957a).

In preliminary surveys of the mealybugs present on cacao in Nigeria, Sutherland (1953) and Donald (1954, 1955) found that species of the genus *Planococcus* Ferris were relatively much more abundant than at Tafo. However, their results were similar to those obtained in Ghana in that the size and composition of the mealybug population on cacao was found to vary with site and with season, but was generally at a low level. Clearly the mealybugs of cacao are not direct pests of cacao and are of little economic importance except as vectors of swollen shoot disease. Consequently, there is little justification for attempting to control the limited populations which do occur, except in areas where the disease is present.

The factors influencing the number of mealybugs occurring on cacao are not fully understood, but the low populations which have been observed may be due, at least in part, to the control exerted by indigenous parasites and predators. Many species of Hymenoptera are primary parasites and the predators include larvae of the families Cecidomyiidae (Diptera), Coccinellidae (Coleoptera) and Lycaenidae (Lepidoptera). Observations on the occurrence and

distribution of the natural enemies of cacao mealybugs are presented by Strickland (1947, 1951a, 1951b), Sutherland (1953), Donald (1954, 1956) and Cornwell (1957a). Their data show that the level of parasitism is not high although the effect of predators may be more important. It was considered that a reduction in the rate of spread of swollen shoot disease might be achieved by increasing this natural level of biological control of the mealybugs through the introduction of exotic natural enemies.

In some of the first tests Nicol, Owen & Strickland (1950) found that two strains of a fungus, *Aspergillus parasiticus* Speare, which was introduced from America, would attack *P. njalensis* and kill most of the individuals treated in laboratory tests. However the fungus was not effective under field conditions and it was concluded (Nicol, 1953a) that the general control of mealybugs in this way was not practicable.

The first attempt at biological control of the mealybugs on cacao in West Africa using insects, was made when Posnette & Strickland (1949) introduced a race of the hymenopterous parasite *Anagyrus kivuensis* Compere from Kenya and reared specimens in the laboratory on three local mealybug species. Further work was carried out in collaboration with the Commonwealth Bureau of Biological Control and has been summarised by Nicol (1953a) and in the Annual Reports of the West African Cocoa Research Institute (April 1950-March 1951 *et. seq.*), while Decker and Donald are to prepare a detailed account of the work as a separate technical bulletin. In the course of the investigations, specimens of nineteen different species of parasite were introduced into Ghana, along with 35,000 adult coccinellid beetles of five different species from California. Most of the beetles were released on arrival, while the parasites were first tested in the laboratory to determine whether they would attack the commoner mealybugs occurring in Ghana. The six most promising parasites were selected, reared in large numbers and half a million individuals eventually released at five localities.

For some years only limited numbers of mealybugs were collected in the release areas and the introduced insects were given every opportunity to survive. Nevertheless, it appears that none of the introduced species have had any detectable effect on the local mealybug populations. Indeed the collections suggest that only one has become permanently established. This is a hymenopterous parasite *Pseudoaphycus angelicus* Howard which has been recovered in small numbers near two of the release areas. The results obtained to date are obviously not encouraging and no further releases are to be made, although routine collections of mealybugs will continue, with the object of obtaining additional information on the establishment of the insects already released.

D. Eradication Measures

Resistant or tolerant varieties, mild strains of virus, biological control or the use of insecticides may all be used in the future; but at the present time the general method of controlling swollen shoot disease is to remove all the infected trees as they are discovered and in this way attempt to arrest spread by eradicating the obvious sources of infection. This is the basic method of control which has been adopted at the Central Cocoa Research Station (Posnette, 1943b), the West African Cocoa Research Institute (West, 1950; Benstead, 1953a) and by the Departments of Agriculture in Ghana (Ross & Broatch, 1951; Broatch, 1953, 1955; Moss, 1953a; Hammond, 1957) and in Nigeria (Lister & Thresh, 1955).

The Survey System

At the present time examining trees for symptoms at regular intervals is the only practical method of detecting infection in the field. Chemical methods of diagnosis have been tried (Hancock, 1949; Tinsley & Usher, 1954), but these techniques are not suitable for use on an extensive scale under field conditions. Consequently the success of the eradication control measures depends to a large extent on the efficiency with which infected trees are spotted during inspections carried out from ground level. To be effective, the eradication measures must be applied promptly and efficiently wherever infected trees are found. It is therefore necessary to inspect all cacao at regular intervals, if it is in areas where swollen shoot disease is likely to occur. The West African peasant farmers cannot be relied upon to carry out these inspections or to remove infected trees and it has been necessary for the government authorities to employ and train large staffs to carry out these essential duties in Ghana and in Nigeria.

The difficulties experienced by the survey parties are formidable. At the outset of the work the cacao buying stations were known, but there was little information on the detailed distribution of the actual growing areas. These were often in remote or difficult country and the survey parties were greatly hampered by the lack of adequate maps and access roads (Hadland, 1951). Moreover, the magnitude of the task was enormous. In Nigeria alone more than a million acres of mature cacao were recorded during the initial survey and the annual cost of the inspection service now amounts to some £170,000. The acreage of cacao in Ghana is even greater and is not less than four million acres, while the cost of the routine control measures against swollen shoot disease, including the routine surveys, accounts for 80 per cent. of the total expenditure of the Department of Agriculture on cacao (Hammond, 1957).

The difficulties experienced by the survey parties are not solely

due to the inaccessibility of some of the cacao farms and it has been found in Ghana and in Nigeria that symptoms are not always easy to find on infected trees (Posnette & Todd, 1951; Thresh, 1958). At one outbreak in Nigeria where cutting out measures were delayed, almost 20 per cent. of the 1,324 trees found with symptoms in May 1955 were symptomless when examined during the dry season, nineteen months later. This is a surprisingly high percentage, but comparable figures have been obtained in more detailed observations carried out at an infected farm near Ibadan. On this farm approximately 10 per cent. of the trees which were known to be infected were symptomless at any one time. Symptoms tend to be least conspicuous during the dry season, when leaves with symptoms may be lost or swellings destroyed as a result of the extensive defoliation or damage to the shoots and branches which is caused by capsid attack or die-back. Similarly, symptoms are also difficult to find during the cool cloudy conditions at the height of the rainy season, when the trees make little new growth. These variations in symptom expression have an important effect on the efficiency of the routine survey operations and explain, at least in part, the observation that most new outbreaks are found at the beginning and towards the end of the wet season, when trees are growing vigorously and showing conspicuous leaf and stem symptoms. It also follows that the chances of finding outbreaks of virus are at a minimum in areas which receive an annual inspection during the dry season or at the height of the rains.

In view of the many difficulties experienced by the survey parties it is hardly surprising that many outbreaks are missed for some years, before they are eventually discovered at a stage when hundreds or even thousands of trees may have become infected (Lister & Thresh, 1957b). Ideally, outbreaks should be detected soon after their inception, at a stage when they can be easily eradicated and before they have become major foci of infection. That this can be achieved on a small scale has been established on the cacao of what was the Central Cocoa Research Station at Tafo, Ghana (Posnette, 1943b). Here, closely supervised survey parties examined the 65 acres of mature cacao at monthly intervals and usually detected new outbreaks before these involved more than a few infected trees. Obviously an inspection service operating over the whole of the cacao areas in Ghana and in Nigeria which is consistently capable of detecting new outbreaks before they involve more than ten infected trees would be prohibitively expensive. Nevertheless, it is clear that efforts should be made to ensure that the existing survey parties are detecting new outbreaks with reasonable efficiency, as this is one of the most important aspects of the eradication policy.

The Treatment of Outbreaks on Discovery

When outbreaks of virus are found by the survey parties, destroying the trees actually found with symptoms is not usually sufficient to eradicate virus from the area. This was established by Posnette (1943b) from experience gained in attempting to control swollen shoot disease at the Central Cocoa Research Station at Tafo, and the observation has been repeatedly confirmed elsewhere in Ghana and in Nigeria. The reason for the frequent failure of simple cutting out measures to give immediate control is that an inspection carried out from ground level does not usually reveal all the infected trees in an outbreak. As a result, missed infections are often left behind and may act as sources of virus to feeding mealybugs, even though the trees are not showing symptoms (Thresh, 1957). These infected but symptomless trees are particularly dangerous, as they are likely to support a higher mealybug population than trees in a more severe stage of infection (Cornwell, 1956). Consequently a cutting out policy involving only the removal of trees found with symptoms is an inefficient method of eradicating virus outbreaks and the disease may continue to spread around outbreaks which have been treated and retreated many times. An example of spread occurring in this way is given by Hanna & Heatherington (1957), who present details of cutting out operations carried out in the cacao of three partially infected farms in Ghana, between November, 1952 and September 1954. A total of 2,963 trees were found with symptoms and destroyed during the initial treatments and the remaining trees were then kept under regular monthly re-inspection for twenty-two months. Records show that a total of 2,412 infected trees were found and cut out during the monthly re-inspections, and that retreatments were necessary in each farm in each month. Moreover, there was no obvious decline in the rate at which infected trees appeared. The lack of success of the cutting out operations at these farms is not atypical and virus has been eradicated from only 2 per cent. of the farms in Ghana where it has been possible to cut out only trees actually found with symptoms. The limitation of the cutting out policy adopted in Ghana is also shown by the fact that the number of infected trees cut out during the retreatment of virus outbreaks is almost half the number cut out during the initial treatments (Hammond, 1957). It should be pointed out, however, that the opposition encountered when cutting out treatments were resumed in Ghana in 1948, made it impossible until 1957 to carry out more drastic eradication measures, even though these were known to be more efficient.

Recent observations made at a number of virus outbreaks in Nigeria have shown (Thresh, 1958) that the infected trees which are

missed and left behind after an initial cutting out treatment can be divided into several groups:

1. Trees which are showing symptoms but are missed by the inspection parties, because the symptoms on them are difficult to spot during a routine inspection from ground level.

2. Recently infected trees which have not produced symptoms at the time the inspection is carried out.

3. Trees which are infected with very mild strains of virus and which are almost symptomless and virtually impossible to detect during a routine inspection.

4. Trees which are tolerating infection with a severe form of virus and which are symptomless or showing very inconspicuous symptoms.

The relative distribution of these latent and missed infections into the four categories has not been studied in detail, but observations in Ghana (Posnette & Todd, 1951, 1955) and in Nigeria (Thresh, 1958) suggest that relatively few trees are missed by the inspection parties because they are tolerating infection, or showing the inconspicuous symptoms of a mild strain. Moreover, the trees in these categories often occur within and not on the edge of outbreaks, so that most of them are near obvious infections and can be destroyed if all the trees found with symptoms are cut out along with the immediately adjacent apparently healthy trees. It appears that most of the infected trees which are missed by the survey parties are in the latent phase of infection and trees in this category present a particular problem, because the latent period is very variable and can range from thirty-five days to more than two years (Posnette, 1947a; Crowdy & Posnette, 1957; Lister & Thresh, 1955). Moreover, the latent infections may be widely distributed in the vicinity of an outbreak, according to the pattern of spread.

The established facts on mealybug behaviour (Strickland, 1950, 1951a; Cornwell, 1955, 1957b, 1958) indicate that the spread of swollen shoot disease may occur in two distinct ways – as a result of mealybugs walking through the canopy branches from infected trees to adjacent healthy ones and by the dispersal of mealybugs over considerable distances by wind currents. Most trees are probably infected as a result of limited movement through the canopy and this explains the observed tendency for outbreaks to spread radially outwards, as new infections appear in close proximity to those already showing symptoms. However, the dispersal of mealybugs through the air, although less frequent, is of great importance and accounts for spread over considerable distances and for the appearance of infection in cacao remote from any source of virus.

Observations on the pattern of spread of swollen shoot disease have been made in Ghana (Posnette, 1943b) and in Nigeria (Lister & Thresh, 1957b; Thresh, 1958, unpublished information). In the Nigerian experiments the apparently healthy trees around ninety-seven outbreaks were coppiced to a distance of 30 yds. from the nearest tree with symptoms and the coppicing method was used as an indexing technique for demonstrating the presence of latent and missed infections. There was found to be great variation in the number and distribution of infected stumps found at the coppiced sites, even around outbreaks of similar size, but in general more infected stumps were found around large outbreaks than around small ones. However, the ratio of infected stumps to the number of standing trees found with symptoms at the time of coppicing was at a maximum for the smallest outbreaks, indicating that these are spreading at a more rapid rate than large ones. This conclusion is substantiated by observations made on the uninterrupted spread of virus in infected farms and is to be expected from the fact that the ratio of infected trees to healthy trees in contact with them is at a minimum for the smallest outbreaks.

The number of infected stumps occurring around the treated outbreaks decreased rapidly with increasing distance from the infected trees which were found with symptoms and cut out at the time of coppicing. Of the infected stumps occurring within 30 yds. of the cut out trees, 51 per cent. occurred within 5 yds., 35 per cent occurred between 5 and 10 yds., 8 per cent. occurred between 10 and 15 yds. and the remaining 6 per cent. occurred between 15 and 30 yds. Many of the infected stumps were of trees which were in the initial latent phase of infection at the time they were coppiced. The steep gradient of their occurrence around the treated outbreaks is therefore consistent with the observation that cacao swollen shoot virus spreads slowly compared with other viruses and particularly when compared with the spread of certain fungi. The steep gradients are also consistent with the suggestion that most of the spread of cacao swollen shoot virus takes place by the movement of mealybugs for a limited distance through the cacao canopy and to a much lesser extent by the windborne spread of mealybugs through the air.

The distribution of infected stumps was similar around outbreaks of all sizes, but the intensity of infection in the stumps around large outbreaks was higher than the intensity around small ones. Around outbreaks containing more than fifty infected trees 8.6 per cent. of the stumps which occurred within 30 yds. were found to be infected, compared with 2.7 per cent. infection in the stumps around outbreaks containing six to fifty infected trees and 1.4 per cent. infection in the stumps around the smallest outbreaks. Clearly, therefore, to eradi-

cate virus by cutting out operations it is necessary to destroy the apparently healthy trees around large outbreaks to a greater depth than around small ones. However, the number of apparently healthy trees destroyed around outbreaks tends to increase as the square of the distance to which they are cut. This means that on deciding the routine cutting out measures to be adopted for the treatment of outbreaks, it is necessary to balance the additional control achieved by making the treatment more drastic, against the extra cost and the wastage of healthy trees which this would involve. Data collected from the Nigerian coppicing experiments enable this to be done and the provisional recommendations which have been made from an analysis of the results are that all trees found with symptoms should be uprooted and the adjacent apparently healthy trees cut out or coppiced to a depth of 5, 10 and 15 yds. around outbreaks consisting of one to five, six to fifty and more than fifty infected trees, respectively. Similar recommendations probably apply also to the treatment of outbreaks in Ghana, but further information is required on this point. It is possible that differences in the growing conditions, in the range of viruses present, or in the size, composition and behaviour of the cacao mealybug populations in Ghana, as compared with Nigeria, will make it necessary to introduce modifications in the proposals.

If it becomes possible to treat all outbreaks of virus found in Nigeria and Ghana according to the methods based on the results of the recent coppicing investigations, it seems that many outbreaks will be eradicated by initial cutting out treatments which are likely to involve only a small proportion of healthy trees. However, not all the outbreaks will be eradicated by such simple methods and infected trees are likely to be found during one or more of the reinspections carried out around some of the cut out areas. Outlying infections found in this way are often referred to as satellite outbreaks, and they have probably been infected by the movement of windborne mealybugs from the originally treated centres of infection.

Recent investigations in Nigeria (Thresh, 1958) have shown that, as might be expected, satellite outbreaks occur with the greatest frequency around the larger centres of infection, although some outbreaks have many outlying infections associated with them, whereas others of a similar size have few. It has also been established that the probability of satellite outbreaks occurring around a centre of infection decreases with increasing distance from the centre. These observations do not provide a reliable basis for predicting the distribution and occurrence of satellite outbreaks at the time an initial treatment is carried out. Moreover, the outlying infections usually represent only a small proportion of the trees around an outbreak and they do not occur with sufficient regularity to justify more

drastic initial cutting out treatments. The movement of windborne mealybugs cannot be prevented and it follows that the only provision which can be made at present for the occurrence of satellite outbreaks is to carry out regular and thorough inspections of the standing trees surrounding each cut out area, particularly the larger ones and those around which outlying infections have already been found. Satellite outbreaks would also be less of a problem if outbreaks could be detected by the survey parties at an early stage and before they have become major foci of infection from which there is a high probability of infective mealybugs being carried away by windcurrents.

Coppicing as an Adjunct to Cutting Out

An alternative method of dealing with the suspect but apparently healthy trees immediately around an outbreak is to coppice them and not completely cut them out. The possibilities of this method as an adjunct to cutting out the trees actually found with symptoms were suggested by Berkeley, Carter & Van Slogteren (1948) and have been investigated in the experiments carried out in Nigeria (Lister & Thresh, 1957b; Thresh, 1958). Most of the trees which were coppiced produced shoots which showed conspicuous symptoms if they were infected, and it was found that the technique could be used to index the apparently healthy trees for infection, as well as providing a method of preventing virus spread from the suspect trees. Any stumps on which shoots with symptoms were not found were allowed to grow on and as the growth was extremely rapid, some trees were bearing pods in the second year after being cut back (Thresh, 1957). Coppicing the apparently healthy trees around virus outbreaks has some advantages over cutting them out. No healthy trees are intentionally destroyed during the course of the treatments and also the problem of replanting cut out trees is to some extent avoided. However, the coppicing modification is not recommended, because it causes additional problems. Not only is it necessary to inspect the coppiced stumps at regular intervals, but the regeneration growth has to be sprayed regularly against capsids, otherwise extensive damage occurs. Moreover, as infected trees have to be replaced by seedlings, some replanting is inevitable and to combine this operation with the maintenance of coppiced cacao causes difficulties in organising the routine rehabilitation work and tends to waste labour (Rowe, unpublished information).

The Eradication of Wild Hosts

Transmission tests have shown that naturally occurring specimens of *Ceiba pentandra* Gaertn., *Cola chlamydantha* K. Schum., *Cola gigantea*

var *glabrescens* Brenan et. Keay and *Adansonia digitata* L. may be infected with viruses which can be transmitted to cacao by mealybugs (Posnette, Robertson & Todd, 1950; Todd, 1951b; Attafuah & Tinsley, 1958). The significance of these plants as hosts of cacao viruses is difficult to evaluate and depends upon the incidence of infection, the mealybugs they support and their proximity to healthy cacao. However, *C. chlamydantha* appears to be an important source of infection in the Western Province of Ghana and it is recommended that the tree should be destroyed wherever it occurs in cacao farms or in areas which are being cleared for the establishment of cacao.

C. chlamydantha trees grow to moderate size and they can be cut out without great difficulty, but *C. pentandra* trees may be as much as 200 ft. high and if they occur in cacao and are killed, they usually cause damage over an extensive area. As a result, it has been recommended that *C. pentandra* trees should be eradicated only from farms where the cacao has been cut out, or from areas of bush which are being cleared for planting. A similar suggestion has been made for dealing with other naturally occurring relatives of cacao (Benstead, 1953b). Only some of these species have been shown to be susceptible to cacao swollen shoot virus (Posnette *et. al.* 1950; Tinsley & Wharton, 1958). However, they have no great value as shade trees and it is a reasonable precaution to have them removed.

Virus infection in cacao and in *A. digitata* has been found to occur together at only one locality in Ghana (Attafuah & Dale, 1957) and the indications are that infection in *A. digitata* has little relevance to the incidence of cacao viruses. Until further information is obtained on this point it is not considered justifiable to recommend the destruction of *A. digitata* trees, particularly as these usually occur in areas remote from the nearest cacao and are used to supply a range of products of considerable local value (Attafuah & Tinsley, 1958).

When the possible significance of wild hosts had been appreciated, Mapother (1955) investigated methods of killing the large forest tree relatives of cacao by chemical methods. It was hoped that a method could be found of killing trees slowly, so that they disintegrated over a period of months and caused less damage to adjacent cacao than the usual but inconvenient and expensive method of felling. Sodium arsenite and esters of 2, 4, 5 – trichlorophenoxyacetic acid were the most active of the twelve preparations which were tested, although it was found that some of the trees, particularly the larger ones, took up to three years to die. Usually the poisoned trees disintegrated slowly and damage to less than ten cacao trees was recorded for each tree killed in the experiments.

Wild hosts of the various mealybug species which occur on cacao are too numerous and frequent in occurrence to eradicate. However

individuals of *Canthium sp.* may support populations of several thousand *P. njalensis* and the associated ant *Crematogaster africana* Mayr (Strickland, 1951a). *Canthium sp.* occurs commonly in and around cacao farms in parts of Ghana at a density of 1 on every 2 or 3 acres. The tree is not a host of cacao virus but may be an important source of mealybugs and ants and wherever practicable it should be eradicated.

The Replanting of Cut Out Areas

Eradication measures provide a method of checking the spread of virus and if successfully practised on a large scale they may prevent any further major deterioration in the swollen shoot disease position in West Africa. However, they can do no more than this and to maintain yields in countries where control measures are practised, it is essential that new plantings should be made and be coming into bearing on a scale sufficient to compensate for the yield of trees destroyed in cutting out operations.

In Ghana and in Nigeria, survey data for the countries as a whole show that trees are coming into bearing at a rate several times that at which trees are being cut out (Moss, 1953b; Broatch, 1955; Hadland, unpublished information). This is a satisfactory situation and indicates that in the immediate future yields are likely to be maintained, or even increased, in both countries. However, most of the young cacao is being planted in new areas and not to replace cut out trees. In Ghana, for example, approximately 126,000 acres of cacao had been cut out by the end of June 1957 but by that date only 16,271 of these acres had been certified as satisfactorily replanted. Similarly, in Nigeria, approximately 3,500 acres had been cut out and less than 150 acres had been replanted by the end of the 1957 season. In many areas there had been insufficient time to establish the necessary shade before attempting to replant, but there are various other reasons for the limited amount of replanting which has occurred. In some localities in Ghana for example, the farmers have moved from areas devastated by swollen shoot disease to previously inaccessible parts of Western Province (Moss, 1953b). In other parts of Ghana and to a greater extent in Nigeria, the soils have been unsuitable for replanting cacao; while in one of the areas of Nigeria where control measures have been abandoned it had been a deliberate policy of the Department of Agriculture to replant cut out areas with oil palms or citrus and not with cacao (Thresh, 1958).

The indications are, therefore, that in certain localities in Ghana and Nigeria the population of cacao trees is tending to fall as a result of cutting out operations and the failure to replant on an adequate scale. This means that in these areas swollen shoot disease is not being

contained in the strict sense of the term as used by Carter, who considered that 'swollen shoot can be said to be contained only if and when new cacao is coming into bearing in the affected areas at the same or at a faster rate than bearing trees are being cut out' (unpublished report on a visit to WACRI, 1957). Nevertheless, cacao can be successfully planted and brought back into bearing, without serious losses due to swollen shoot disease, even in the most heavily infected areas. At Tafo, for example, seedlings have been planted to replace trees cut out in routine control operations on the Old Station since 1940 and on the Square Mile since 1946, yet only a small proportion have been found with symptoms and cut out (Benstead, 1951, 1953a). Similarly, at the four WACRI Substations in Ghana, heavily infected farms have been cleared, replanted and brought back into bearing, even though the cacao was planted in areas of extensive infection. Less than 1 per cent. of the seedlings became infected in the six years after planting and most of the infections which did occur were on the perimeters of the plots and adjacent to infected trees in peasant farms.

The agronomic problems involved in replanting cut out areas are beyond the scope of this review and are discussed by Benstead (1951, 1953b). However, some of the most favourable cacao growing areas in Ghana and in Nigeria are those in which infection is at present widespread. The available evidence indicates that these areas could be successfully rehabilitated and brought back into something approaching full bearing, by eradication measures combined with replanting. Clearly, it would be advantageous to select the better soils and use the best available planting material. Also, it is essential to plant in the largest possible blocks and bring the cacao under regular inspection. If these conditions are fulfilled, then the annual losses due to swollen shoot disease are likely to be small and it is possible that these losses may be further reduced by the use of resistant varieties, mild strain protection or insecticides. A further possibility, suggested by Cornwell (1958), is that coffee or other crops which are not susceptible to cacao swollen shoot virus should be planted as barriers around areas of healthy cacao, to intercept the mealybugs coming in and carrying virus from outside. All these various possibilities are discussed elsewhere in this review and may eventually necessitate a change in policy in the routine control measures against swollen shoot disease.

The eradication measures used at the present time in Ghana and Nigeria, provide an opportunity of changing the present system of cacao cultivation in West Africa. If the heavily infected areas can be successfully rehabilitated, using the best available varieties and methods, then it is possible that yields per acre will be increased above the present unsatisfactory level. This would have important consequences and may make it possible to abandon disease control

operations in marginal areas, where it is difficult to replant cut out trees, or in uneconomic cacao, where yields are inadequate to support the cost of even the simplest disease control operations.

The necessity for intensifying the present system of growing cacao in West Africa has already been stressed by Thresh (1956) and by Crosbie (1957). These views are consistent with those previously expressed by Havord (1955) and Jolly (1955) from their experiences in Trinidad and by Crowdy & Elias (1956) from a general consideration of the economic aspects of pest and disease control.

E. The Use of Insecticides

As already pointed out, the routine control of mealybugs on cacao is not justified, nor is it likely to be economic if carried out by chemical methods. However, insecticides would be of obvious value if they could be used specifically to increase the efficiency of the routine eradication control measures against swollen shoot disease. This was appreciated at an early stage of the investigations and laboratory and field trials have been carried out to find chemical methods of controlling the mealybugs on the apparently healthy trees around virus outbreaks, where all the trees showing symptoms have been removed. It was hoped that the use of insecticides in this way would prevent any possible spread of virus from the missed and latent infections before they were eventually found with symptoms and cut out during the reinspections and retreatments. If this can be achieved at reasonable cost it will no longer be desirable to cut out trees before they are actually found with symptoms and it might also be possible to reduce the frequency with which the trees around treated outbreaks have to be reinspected.

Contact Insecticides

Preliminary laboratory tests carried out by Nicol (1950) showed that exposed mealybugs were readily killed by a range of insecticides including nicotine sulphate, parathion and D.D.T. These and other materials were then used in sprays, fogs or dusts to determine their effect on the natural mealybug populations on small trees (Mapother & Nicol, 1953). Most of the mealy bugs on the treated trees were attended by ants and protected by the usual carton tents. Consequently only limited control was achieved and the most successful chemicals were parathion and nicotine, which appeared to be acting as fumigants. It was concluded that the chemicals would have been even less effective if they had been applied to full-sized trees of farmers' cacao and no further tests were carried out using these materials and methods of application.

Systemic Insecticides

Preliminary tests carried out by Nicol (1952) and Hanna, Heatherington & Judenko (1952) showed that some systemic insecticides were absorbed through the roots of cacao plants, which then become toxic to mealybugs feeding on the aerial parts. Dimefox (bis-dimethylamino fluorophosphine oxide) was the most toxic of the insecticides tested and this material was used in a comprehensive series of field experiments carried out at Tafo by the staff of Pest Control Ltd., (Hanna, Judenko & Heatherington, 1955). It was found that dimefox watered on to the soil around cacao trees or applied in smaller quantities by the trunk implantation method (Hanna & Nicol, 1954) killed most of the mealybugs on the trees treated with dosages which had no obvious phytotoxic effects. Treated plants remained toxic to mealybugs for several weeks after treatment and dimefox was clearly far more effective than the contact insecticides used in earlier work. Furthermore its toxicity to mealybugs was unaffected by the presence of ants and the insecticide could be applied readily and quickly by simple techniques, which made it unnecessary to use mechanical spraying apparatus to obtain an adequate coverage of the trees. The main disadvantages in the use of dimefox are that it is dangerously toxic to mammals and has to be handled with great care, while there is evidence that cacao prepared from treated trees has an undesirable flavour (Nicol, 1953b).

There are obvious possibilities in the use of dimefox to supplement the routine control measures against swollen shoot disease, but these have been investigated in only one somewhat inadequate experiment. This was carried out in Ghana and is described by Hanna & Heatherington (1957). The trees on a 13 acre plot of peasant cacao were examined and 1,266 were found with symptoms and cut out in August 1952. Dimefox had previously been applied to the roots of all the trees in June 1952 and applications were repeated at eight-week intervals until September 1953. The dosages applied were based on the girth/weight correlations established in previous experiments (Hanna, *et. al* 1955). After the initial cutting out treatment the remaining trees were examined monthly and a total of 630 were found with symptoms and cut out by August 1955. Retreatments were necessary in all but three of the thirty-six months, but 81 per cent. of the trees which were cut out during the retreatments were found during the first twelve reinspections. By comparison, plots which were not exactly comparable were not treated with dimefox and trees were found with symptoms at every reinspection, while the total number found was similar to the number cut out during the initial treatments (see p. 14). Moreover there was no decrease in the rate at which infected trees were found

on the untreated plots during the retreatments. The interpretation of these results is equivocal but they give limited evidence that the dimefox applications were successful in checking the spread of virus after the initial cutting out treatment. However this success was only achieved at an estimated minimum cost of 32/7d. per tree. Obviously no general recommendations can be made on the evidence of this preliminary, costly, and inadequately controlled experiment, but further work is justified. Particular attention should be given to the possibilities of obtaining efficient systemic insecticides which are not toxic to mammals and it is also possible that comparable results can be obtained by the less frequent application of insecticide.

Formicides

The populations of *P. njalensis* and other common mealybugs on cacao are closely associated with the presence of Crematogasterine ants (Strickland 1951b; Hanna, Judenko & Heatherington, 1956; Cornwell, 1957). The precise nature of this association is incompletely understood, but the ants feed on the honey dew secretion produced by the mealybugs. Consequently the growth of moulds around the colonies is largely prevented and this appears to have a beneficial effect on the mealybug population (Hanna, *et. al.*, 1956). However, there is conflicting evidence on this point and in partially controlled conditions Strickland (1951b) observed that after six months, seedlings infested with *P. njalensis* and *Crematogaster africana* Mayr supported higher mealybug populations than seedlings on which the ant was not present.

It follows from the work already carried out on the association between ants and mealybugs, that instead of using insecticides to kill mealybugs directly, a possible alternative is to destroy the attending ants. This approach has been successful in controlling mealybugs on other crops and investigations into the possibilities of the method have been carried out with the mealybugs on cacao. In some of the earliest experiments Hanna, *et. al.* (1956) greatly reduced the mealybug population on mature cacao trees by spraying twice with 0.2 per cent. D.D.T., after all the dead branches containing ants' nests had been removed and the trunks of the trees had been banded with grease. Efforts to simplify this procedure were unsuccessful and spraying trees with D.D.T., or D.D.T. and parathion, without removing the nests or banding, produced only a partial kill of the mealybugs on treated trees. It was concluded that D.D.T, was not sufficiently persistent or toxic to ants to provide a convenient method of reducing the mealybug population.

Aldrin, dieldrin and chlordane are very toxic to the ants occurring on cacao (Mapother & Nicol, 1953) and these materials have been

used in the most recent experiments on ant control (Taylor, 1957). Dieldrin applied to the trunks of cacao and forest species at the rate of 1 lb. toxicant per acre virtually eliminated the ant population and the re-establishment of the ant nests and organised activity was very slow. The decline in the ant population was accompanied by a striking decrease in the numbers of *P. njalensis*, although other mealybugs which are not commonly attended by ants were relatively unaffected by the formicidal spray and remained at a low level throughout the experiment. The decline in the populations of *P. njalensis* was largely due to an increase in attack by fungi but there was also a temporary increase in the level of parasites. The populations of *P. njalensis* remained very low for some weeks after treatment and recovered slowly.

In further experiments dieldrin is being applied to the apparently healthy trees around virus outbreaks in an effort to arrest spread, as in the previous work with dimefox. It is too early to make an assessment of these experiments, but the success of the formicide sprays in reducing mealybug populations indicate that the use of these sprays may greatly increase the efficiency of the eradication measures.

The Effect of Capsid Control

The spectacular results of the recent spraying experiments carried out on mature trees in Ghana and in Nigeria, indicate that the use of insecticides for the control of capsids will become a routine operation in cacao culture in West Africa. If the use of insecticides in this way does become general then important side effects on the mealybug populations of sprayed trees are to be expected, particularly if the insecticides used have a direct effect on mealybugs, on their parasites and predators or on the attending ants. The magnitude and even the direction of the effect on the size and composition of the mealybug population on sprayed trees is difficult to predict, although populations may be expected to decrease. This is because trees which are brought back into a good condition as a result of spraying are unlikely to provide the lesions and cankers which appear to be the most favoured breeding and feeding sites for mealybugs (Strickland, 1951b; Donald, unpublished information). Moreover, sprayed trees may be expected to support low populations of the Crematogasterine ants which commonly nest in the dead twigs and branches caused by capsid attack and subsequent invasion by fungi (Strickland, 1951b, Hanna, *et. al.* 1956).

Although mealybugs and Crematogasterine ants may occur in lower numbers on trees which have been sprayed against capsids, it does not necessarily follow that virus spread will be stopped or slowed down on such areas. Indeed, Strickland (1951b) was unable to show

any close association between virus incidence and mealybug density. Furthermore, sprayed trees are likely to form a dense interlocking canopy which is more favourable to mealybug movement from tree to tree than one which is broken as a result of capsid attack.

The effect of routine spraying against capsids on the rate of virus spread remains to be determined. However, there is already some evidence that virus symptoms are more readily seen on trees which are in a reasonable condition as a result of spraying, than they are on trees which are extensively damaged by capsid and fungal attack. This may mean that it is unnecessary to inspect sprayed trees at the present frequency, particularly if the rate of spread can be reduced by spraying. It is also possible that sprayed trees which become infected with virus deteriorate less rapidly than trees which are not sprayed. These are important points which require invesigation, as they may be of considerable significance to the Departments of Agriculture responsible for planting cacao in areas of extensive virus infection.

The Control of Mealybugs on Felled Trees

In some of the earliest efforts to eradicate outbreaks of swollen shoot disease, Posnette (1943b) attempted to increase the efficiency of the cutting out measures by spraying infected trees with nicotine sulphate before they were destroyed. The vectors of swollen shoot disease were not known at the time, but it was thought that the treatment might prevent spread occurring as a result of the scattering of insects from the infected trees as they were felled. The results of the experiments were inconclusive, but there was no indication that nicotine was having any effect on the success of the eradication measures.

Further experiments were carried out after it had been established that mealybugs were responsible for the spread of swollen shoot disease and Strickland (1951a) investigated the fate of mealybugs on infected trees which were cut out in Ghana. No observations were made on the number of mealybugs dislodged during the felling operations, but a limited amount of movement took place from the felled trees. Some mealybugs were able to establish themselves on adjacent standing trees, particularly when they were assisted by ants. However, establishment was on a small scale and usually occurred over a short distance and after virus became unavailable in the felled trees. It seemed that there was little danger of virus being spread by the movement of mealybugs from cut out trees. This conclusion was substantiated by more detailed investigations carried out by Cornwell (1956), who investigated the fate of mealybugs on felled trees, when these had been made into slash piles. Conditions within the slash

piles were temporarily favourable for reproduction and most of the mealybugs made no attempt to move to other hosts. Few of those which did move were able to establish themselves and it is clear that there is little justification for controlling the mealybugs on infected trees before these are felled.

SUGGESTIONS FOR FURTHER WORK

In each section of this bulletin, attention has been drawn to aspects of the work on swollen shoot disease on which information is lacking or inadequate. For convenience, the suggestions which have been made for further investigations are summarised in this section. No attempt has been made to allocate an order of priority as the future programme of work at the West African Cocoa Research Institute will depend to a large extent on the policies adopted by the West African Departments of Agriculture and also on the scientific staff available to carry out the work.

Resistant Varieties

The limited work which has already been carried out indicates that the use of resistant varieties has great potential in the long term approach to the control of swollen shoot disease. All aspects of this work require investigation and the points on which information is required include a study of:

1. The field behaviour of material which appears to resist or tolerate infection in laboratory tests carried out on seedlings or cuttings.

2. The reaction of plants which resist or tolerate infection with virus from one locality to viruses from other areas.

3. The inheritance of the factors for resistance and tolerance.

4. The most convenient way in which resistant material can be used, whether as rooted cuttings or seedlings of known parentage.

5. The possibility of obtaining genes for resistance, or even immunity, from cacaos not at present in West Africa, or from species related to cacao.

6. The availability of virus to mealybugs feeding on trees which are tolerating infection with a virulent virus and the ease with which these trees can be found with symptoms during routine survey operations.

Mild Strain Protection

There are possibilities of using mild strains of virus to protect plants

from the effects of virulent virus but a number of aspects of the work require more extensive investigation before definite recommendations can be made. Information is required on:

1. The long-term effects of mild viruses on the yield of cacao, particularly of trees which are infected as seedlings or as rooted cuttings.

2. The relationships and possible interactions between mild strains of virus collected from different localities and the various virulent viruses from the areas in which infection is widespread.

3. The ability of cacao infected with a mild virus or viruses to withstand the effects of virulent strains, when the mild strain inoculations are carried out before the material is planted out in the heavily infected areas.

4. The extent to which the spread of virulent viruses can be checked, by inoculating the apparently healthy trees around virus outbreaks with mild virus.

5. The availability of mild viruses to mealybugs feeding on infected trees and the ease with which trees infected with mild viruses may be detected during routine survey operations.

6. The rate of spread of mild viruses and the possibility of them giving rise to virulent forms.

Eradication Measures

The destruction of cacao and forest trees infected with cacao swollen shoot disease is the only measure which can be recommended at the present time for the control of swollen shoot disease and it is likely to be the basic method of control in the immediate future. However, the efficiency of these eradication measures could be increased if more information was available on the following aspects:

1. The latent period of infection in trees infected with cacao swollen shoot virus and the factors influencing symptom expression.

2. The incidence and distribution of latent and missed infections around outbreaks of swollen shoot disease, particularly in Ghana where there is little information at the present time.

3. The rate and pattern of virus spread and the possibility of predicting the occurrence of satellite outbreaks.

4. The incidence of infection in forest species.

5. The spread of virus into new plantings, in relation to the extent and distribution of infected cacao in the immediate vicinity.

Additional work is also required on the effects of viruses on the growth and yield of cacao and on the possible effects of routine capsid

control on the rate at which trees deteriorate after becoming infected.

Mealybug Studies

Although detailed investigations have already been carried out on the populations of mealybugs occurring on cacao and their control, further research may make it possible to increase the efficiency of the routine eradication control measures.

Information is required on:

1. The decline in the mealybug population which seems to occur when a tree becomes infected with virus, as it is not clear from the previous investigations whether mealybugs move from infected trees to neighbouring healthy ones or whether the populations die out.

2. The effects of routine capsid control by insecticides on mealybug populations and on the rate of virus spread into and within sprayed plots.

3. The association which exists between ants and mealybugs and the decline in the mealybug populations which follows the application of formicidal sprays.

4. The most efficient and economic way in which dimefox or other less toxic systemic insecticides may be used to control the mealybug populations on cacao and increase the efficiency of cutting out operations.

5. The relative importance of wind dispersal and movement from tree to tree through the canopy, as methods by which mealybugs of different species spread swollen shoot disease.

6. The extent and distance to which mealybugs are blown into healthy cacao from areas of mass infection.

7. The incidence and build up of mealybug infestations on young cacao and on the possible methods of maintaining the populations at a low level by the use of insecticides.

8. The possibilities of using cola, coffee or citrus (which are not susceptible to cacao viruses) to form a barrier around plots of healthy cacao and intercept the mealybugs coming in to the plots and carrying virus from outside.

SUMMARY

In 1938, the swollen shoot condition in cacao was shown to be caused by a virus and since that date extensive investigations have been carried out to determine methods of curing infected plants and of checking the spread of the disease in the field. This work is summarised and discussed in the present bulletin which is based on published

papers and numerous references in the Annual Reports of the West African Cocoa Research Institute.

Heat therapy and chemotherapy have failed to cure plants infected with cacao swollen shoot virus and there is no immediate prospect of a therapeutic method being introduced, which can be used on a field scale. Control measures against cacao swollen shoot disease are thus restricted to methods of reducing the spread which normally occurs by the movement of mealybugs from infected cacao, or wild hosts, to healthy trees. Various methods of reducing spread have been investigated and include the use of insecticides, eradication measures and resistant varieties. The use of mild strains of virus to protect plants from the effects of the commoner virulent ones has also been considered. In addition, unsuccessful efforts have been made to control the mealybug populations on cacao in Ghana by the introduction of fungi and exotic insect parasites and predators, to supplement the natural level of biological control exerted by indigenous species.

Cutting out infected cacao trees and some of the naturally occurring hosts of cacao viruses has been the only control measure which it has been practicable to adopt on a widespread scale by the Departments of Agriculture in Ghana and in Nigeria. In these countries, government employees inspect the cacao farms at regular intervals and attempt to eradicate outbreaks as they are discovered. The survey parties responsible for the routine control operations are hampered by the inaccessibility of some of the farms and by difficulties experienced in spotting virus symptoms on infected trees. Nevertheless, they have achieved some success in eradicating outbreaks and in restricting the build up of infection which would have occurred if no control measures had been practised. The eradication measures have been particularly successful in areas where the incidence of virus was not high and where it was possible to destroy the apparently healthy trees immediately around each outbreak.

In the immediate future, eradication measures are likely to be continued as the basic method of controlling swollen shoot disease. However, they may be made more efficient by the use of insecticides to control the mealybugs on the standing trees which occur around treated outbreaks and which may include missed or latent infections. Preliminary results with a systemic insecticide and with formicides have given encouraging results and warrant further investigations, so that definite recommendation may be made.

To maintain production in areas affected by swollen shoot disease it is essential to replant cacao wherever infected trees are cut out. Replanting can usually be carried out successfully on the better soils and the evidence indicates that the annual losses due to swollen shoot disease are small if the new cacao is brought under regular inspection

and is not immediately adjacent to infected trees. In the future it may be possible to decrease the rate at which new plantings become infected by the use of resistant varieties and barrier crops or insecticides may be used to restrict the build up of mealybug populations on the young trees. Alternatively, new planting material may be protected from the effects of virulent virus by the use of mild strains.

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APPENDIX I

TABLE 1

*The number of trees eradicated in attempts to control cacao swollen shoot disease in Nigeria between 1946 and 1956**

Year	*Infected trees cut out*	*Apparently healthy trees cut out*	*All trees cut out*
1946	21,568	0	21,568
1947	192,270	0	192,270
1948	284,127	0	284,127
1949	711,651	0	711,651
1950†	277,298	5,272	282,570
1951	1,787	16,939	18,726
1952	2,027	32,979	35,006
1953†	3,620	47,840	51,460
1954	3,006	43,294	46,300
1955	5,003	51,919	56,922
1956	12,403	76,700	89,103
Total	1,514,760	274,493	1,789,703

* Data from Lister & Thresh (1957).
† Control measures were abandoned in one heavily infected area of Ibadan Province in 1950 and in part of Ilaro Province in 1953.

TABLE 2

*The number of infected trees eradicated in attempts to control cacao swollen shoot disease in Ghana between 1945 and 1957**

Year	*Infected trees cut out*
1945–46	51,832
1946–47	1,211,011
1947–48	1,703,780
1948–49	2,143,222
1949–50	3,166,147
1950–51	3,565,461
1951–52	1,532,679
1952–53	5,455,527
1953–54	7,895,762
1954–55	11,046,471
1955–56	11,425,541
1956–57	11,121,113
Total	60,318,546

* Data from Ross & Broatch (1951), Broatch (1953, 1955) and Hammond (1957).